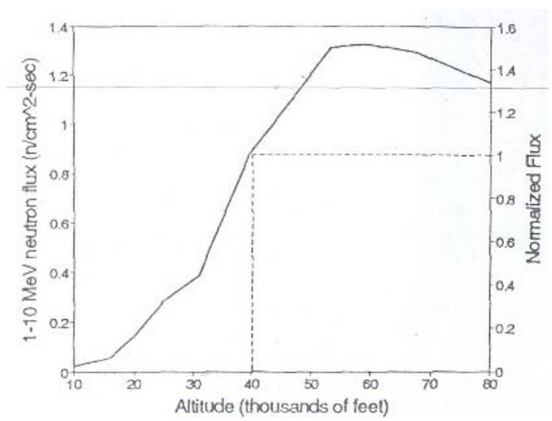
Single Event Upsets in Aircraft Avionics

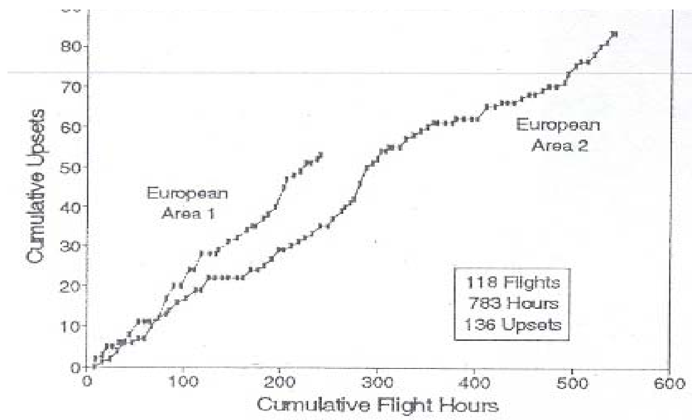
In 2001, the NASA Altair, Unmanned Air Vehicle (UAV) flew its first flight at an altitude of 100,000 feet. Designed by NASA-Dryden engineers and scientists, it is designed to fly for up to 48 hours to complete a variety of science research studies of Earth. For more details about this Dryden program, visit

http://www.nasa.gov/centers/dryden/news/FactSheets

Because of the complexity of the computer systems (called avionics) onboard, and the very high altitudes being flown, special attention had to be paid to cosmic ray showers. These particles, mostly neutrons, pass through the walls of the aircraft and can affect computer circuitry. For unmanned aircraft, the slightest computer glitch can spell the end of an $8 million aircraft. This exercise explores some of the issues behind computer glitches at aircraft altitudes.

Between the high-radiation environment of space, and the comparative safety of the ground, lies the atmosphere. Most human activity in the military and commercial flight industry takes place between ground-level and 100,000 feet. As cosmic rays collide with atmospheric atoms, they liberate showers of particles deep into the lower atmosphere. The most penetrating of these are the charge-free neutrons. The two figures below show the neutron flux versus altitude, and data taken from aircraft flying at 29,000 feet. The data were taken from a research paper by Taber and Normand (1993), and published in the *IEEE Transactions on Nuclear Science*, vol. 40, No. 2, pp 120.





The left-hand curve gives the number of neutrons that pass through each square centimeter of surface every second (the neutron flux). The right-hand plot gives the cumulative number of memory upsets at an altitude of 30,000 feet after a given number of hours in the air.

1. What is the neutron flux at 30,000 feet? At 60,000 feet?

2. How many memory upsets were registered after 400 hours of flight?

3. If the aircraft carried 1560 memory modules (called SRAMS), each with 64,000 bytes of memory, how many bytes of memory were carried? How many binary 'bits' of memory were carried? (1 byte = 8 bits)

4. If each upset involved one bit having the wrong data value due to a neutron impact, how many bit upsets were registered per day?

5. If the area of each memory unit is 7.5×10^{-9} cm^2 ,what is the total area of all the memory modules?

6. How many neutrons passed through this area in one second?

7. During the 400 hours of flight, how many neutrons passed through the memory modules?

8. What is the probability that one neutron will cause an upset?

9. How long do you have to wait for an upset to occur at 30,000 feet? At 60,000 feet? At 100,000 feet?

Answer Key:

The left-hand curve gives the number of neutrons that pass through each square centimeter of surface every second (the neutron flux). The right-hand plot gives the cumulative number of memory upsets at an altitude of 30,000 feet after a given number of hours in the air.

1. What is the neutron flux at 30,000 feet?
From the graph: 0.35 neutrons/cm2/sec

2. How many memory upsets were registered after 400 hours of flight?
From the graph: 60 upsets

3. If the aircraft carried 1560 memory modules (called SRAMS), each with 64,000 bytes of memory, how many bytes of memory were carried? How many binary 'bits' of memory were carried? (1 byte=8 bits)
1560*64000 = 99.8 megabytes x 8 bits/byte = 798,000,000 bits

4. If each upset involved one bit having the wrong data value due to a neutron impact, how many bit upsets were registered per day? 60/(400/24) = 3.6 bits/day for a population of 798,000,000 bits

5. If the area of each memory unit is 7.5×10^{-9} cm^2 ,what is the total area of the memory modules?
$7.9 \times 10^{-9} \times 798,000,000 = 6.3$ cm^2.

6. How many neutrons passed through this total memory area in one second?
From the answers to Problem 1 and 5:
0.35 neutrons/cm^2/sec x 6.3 cm^2 = 2.2 neutrons/second.

7. During the 400 hours of flight, how many neutrons passed through the memory modules?
2.2 neutrons/sec x 400 hours x 3600 seconds/hr = 3.2 million neutrons.

8. What is the probability that one neutron will cause an upset?
From Problem 2 and 7: 60 upsets /3.2 million neutrons= 1 chance in 53,300.

9. How long do you have to wait for an upset to occur at 30,000 feet?
The time it takes 53,300 neutrons to pass through the memory at 2.2 neutrons per second. 53,300/2.2 = 6.7 hours. Or you can get it by 400/60 = 6.7 hours.

At 60,000 feet, the neutron flux is 1.3/0.35 = 3.7 times higher than at 30,000 feet, so you would have to wait 6.7/3.7 = 1.8 hours.

At 100,000 feet, which is the cruising altitude of the Altair UAV, the graph suggests a neutron flux of about 1.0 neutrons/cm^2/sec, so the flux is 1.0/0.35 = 2.9 times stronger at 100,000 feet than at 30,00 feet, and the time between upsets would be about 6.7/2.9 = 2.3 hours.

If the UAV were equipped with this much memory (about 100 megabytes) and was airborne for 48 hours, it would experience 48/2.3 = 21 memory upsets! This is why the computer systems on the UAV have to be radiation-hardened and the software designed to fix radiation errors when they occur.